

An Overview of Nosocomial Infections, Including the Role of the Microbiology Laboratory

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INTRODUCTION: SCOPE AND MAGNITUDE OF THE PROBLEM

Nosocomial infections are a major source of morbidity and mortality, affecting more than 2 million patients annually in the United States (64). In the most comprehensive study on nosocomial infections to date, 5.7% of the 169,526 patients in 338 randomly selected U.S. hospitals developed a nosocomial infection (63). The annual economic burden of nosocomial infections in the United States is estimated to be more than \$4.5 billion in 1992 dollars (97). The extra days, extra charges, and deaths attributed to nosocomial infections vary

by infection site, but together, the adverse consequences of nosocomial infections and their associated costs are substantial (Table 1).

Hospitalized patients are at unusually high risk of infection for various reasons. They tend to be more susceptible to infection because of their underlying disease conditions, but their risk is compounded when they are exposed to certain invasive procedures. If the patient is immunocompromised, microorganisms that are not normally pathogenic are capable of causing disease. Furthermore, the hospital environment supports the acquisition of resistance to antibiotic agents by pathogens, complicating the treatment of infections due to drug-resistant pathogens.

In this review, we will use data from the National Nosocomial Infections Surveillance (NNIS) system, which is

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TABLE 1. Estimated extra days, extra charges, and deaths attributable to nosocomial infections annually in U.S. hospitals^a

Infection type	Avg extra days in hospital per infection	Avg extra charges per infection (1992 dollars)	Deaths directly caused by infections		Deaths to which infections contributed	
			%	Estimated U.S. total	%	Estimated U.S. total
SSI	7.3	\$3,152	0.6	3,251	1.9	9,726
Pneumonia	5.9	\$5,683	3.1	7,087	10.1	22,983
BSI	7.4	\$3,517	4.4	4,496	8.6	8,844
UTI	1.0	\$ 680	0.1	947	0.7	6,503
Other	4.8	\$1,617	0.8	3,246	2.5	10,036
All	4.0	\$2,100	0.9	19,027	2.7	58,092

^a Adapted from reference 97.

conducted by the Centers for Disease Control and Prevention (CDC), and data published by others to describe the epidemiology of nosocomial infections, including the sites of infection, etiologic agents, and antimicrobial agent resistance. The NNIS system is the only source of national data on nosocomial infections and currently consists of 149 hospitals that voluntarily report to CDC their nosocomial infection data, which are collected under standard surveillance protocols and infection definitions (37, 48, 70).

We will focus on endemic infections, i.e., those that occur in an ongoing fashion, rather than epidemic infections, i.e., those that occur in outbreaks, since epidemic infections are estimated to represent only 5% of all nosocomial infections (132). We will discuss current approaches to infection control, particularly those that pertain to patients who are at highest risk of infection, and the essential role of the microbiology laboratory in infection control. We will not discuss in detail the infection control measures used to protect workers in the hospital or laboratory from the risk of infection.

EPIDEMIOLOGY OF NOSOCOMIAL INFECTIONS

The study of nosocomial infections includes understanding the causes of these infections, the characteristics of the patients who become infected, and how often these infections occur. By identifying the characteristics of patients who are at highest risk for infection, we can more effectively direct and prioritize our prevention and control efforts. It also permits us to follow closely the trends of infections that are increasing in incidence, e.g., bloodstream infections (4).

The epidemiology of nosocomial infections has been affected by the introduction of the prospective payment system, which changed the economics of health care delivery in the United States (82, 84, 87). The patients admitted to hospitals now differ from those admitted only a few years ago. More surgical operations are being performed in outpatient settings, and when patients are admitted to the hospital, they are more seriously ill or require sophisticated, and sometimes high-risk, procedures that can be performed only on inpatients. Paradoxically, they are usually discharged from the hospital earlier (104), and their care is usually continued at home or in skilled-nursing facilities. With increasing average severity of illness among hospitalized patients, the infection rate is also expected to increase. The task of monitoring the infection rate is complicated by the difficulty of detecting infections in patients following discharge from the hospital. Postdischarge surveillance for certain infection sites may be necessary for a quality surveillance system and is being urged by some experts (69).

Definitions

A nosocomial infection is one for which there is no evidence that the infection was present or incubating at the time of hospital admission. To be classified as an infection, the condition must be manifested as a clinical disease and not a colonization, which means that microorganisms are present but have no adverse effect on the host. However, an asymptomatic patient may be considered infected if pathogenic microorganisms are found in a body fluid or at a body site that is normally sterile, such as the cerebrospinal fluid or blood.

If surveillance data are to be used to accurately describe the epidemiology of nosocomial infections in the hospital, the definitions of nosocomial infections must be scientifically sound and applied uniformly. The most widely used definitions, published by CDC, contain laboratory and clinical criteria for infections at 13 major and 49 specific sites (48, 70). Infections at almost all of the major sites can be determined by clinical criteria alone, although laboratory results, particularly microbial cultures, provide additional evidence of the presence of an infection. A few infection types require positive cultures, such as asymptomatic bacteriuria and laboratory-confirmed bloodstream infection. These criteria are used to answer three questions that are necessary before an infection is included in the surveillance data: (i) Is an infection present? (ii) At which body site? (iii) Is the infection nosocomial? The preventability of the infection is not a consideration in the decision to include an infection in the surveillance data. Furthermore, surveillance definitions are not intended to define clinical disease for the purpose of making therapeutic decisions. Some true infections will undoubtedly be missed, while conditions that are not infections may be erroneously counted.

Site Distribution

The incidence of nosocomial infections varies by body site and is determined to a large extent by underlying disease conditions in the patients and their exposure to high-risk medical interventions, such as surgical operations and invasive devices. Of all infections reported during 1990 through 1992 by the 80 NNIS system hospitals that reported data from the hospital-wide surveillance component, the most common were urinary tract infections (UTI), followed by pneumonias, surgical site infections (SSI), and primary bloodstream infections (BSI) (Table 2). A variety of infections in other sites are included, such as bone and joint infections, central nervous system infections, and cardiovascular system infections. The order of frequency of the infection sites was similar in hospitals regardless of size and

TABLE 2. Distribution of major infection sites by teaching affiliation and hospital size, 1990 through 1992, hospital-wide component, NNIS system

Infection type	% of cases				
	All hospitals (n = 62,214)	Nonteaching hospitals, <200 beds (n = 1,994)	Nonteaching hospitals, ≥200 beds (n = 12,086)	Teaching hospitals, <500 beds (n = 29,062)	Teaching hospitals, ≥500 beds (n = 19,072)
UTI	33.1	35.9	37.6	32.0	31.5
Pneumonia	15.5	20.4	16.8	14.8	15.4
SSI	14.8	15.2	16.0	14.9	13.9
Primary BSI	13.1	9.6	8.4	12.8	16.9
Other	23.5	18.9	21.2	25.5	22.2

medical school affiliation, except that primary BSI was reported somewhat more often in teaching hospitals. In large teaching hospitals, primary BSI was the second most commonly reported infection after UTI.

Changes in the overall site distribution of nosocomial infections reported during 1980 through 1992 were examined (Fig. 1). The site distributions in each of the time periods show the trend towards fewer UTI and more BSI. While the changes have been gradual and consistent, the reasons are unknown but may partially reflect changes in surveillance methods to focus on certain infection sites. A detailed analysis of temporal trends in BSI rates was unable to determine what portion of the increase in BSI rates in NNIS system hospitals was a surveillance artifact and what portion was a true increase in the incidence of BSI during the 1980s (4).

The distribution of infection sites is considerably different in each of the major hospital services (Table 3). The differences can largely be explained by variations in exposure to high-risk devices or procedures. For example, because patients who have a surgical operation usually are not on the medical service, the number of SSI on the medical service will be small. Similarly, UTI occur infrequently on the pediatric and newborn services because these services rarely use urinary catheters, which are the major risk factor for nosocomial UTI. This illustrates the importance of grouping patients with similar risks before attempting to compare distributions of infections or infection rates (105).

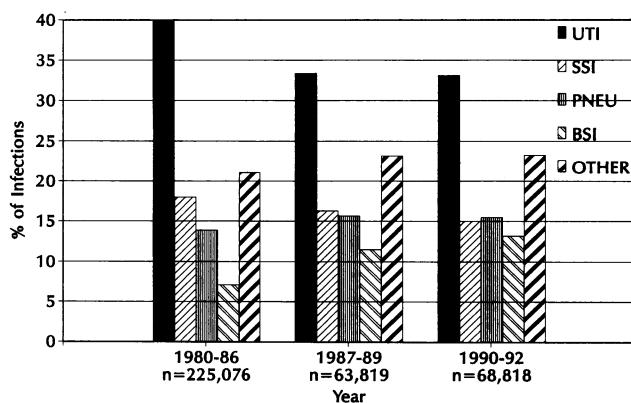


FIG. 1. Trends in distribution of major infection sites by year, 1980 through 1992, hospital-wide component, NNIS system. PNEU, pneumonia.

Ecology

A patient's predisposition to or risk of becoming infected is strongly determined by certain personal characteristics and exposures. These risks are roughly divided into two categories, intrinsic and extrinsic factors (105).

Intrinsic susceptibility of patients to infection. Intrinsic risk factors are those that are inherent in the patient because of underlying disease conditions (Table 4). Knowledge of the intrinsic risk factors is useful for two reasons: special precautions can be employed to protect patients identified as highly susceptible to infection, e.g., patients who are severely immunosuppressed or those who have intravenous catheters may be monitored more closely for BSI or vascular infections; and separate risk-specific rates can be calculated, which permit comparison of rates among patients with similar risks in different hospitals or during different time periods. There has been considerable discussion but limited progress on the difficult task of developing a practical risk index that can be used to adjust the overall nosocomial infection rate (8, 55). The Acute Physiologic and Chronic Health Evaluation (APACHE II) and Diagnosis-Related Groups are two well-known indices for severity of illness and are used to predict the risk of death among intensive-care unit (ICU) patients and resource utilization, respectively. They are less useful when applied to nosocomial infections because the factors associated with increased mortality and improved resource utilization apparently are not the same as those that increase the risk of infection. Patients with very high APACHE II scores probably do not survive long enough to acquire a nosocomial infection. Further study is needed to develop risk indices for adjusting nosocomial infection rates.

Extrinsic factors altering susceptibility to infection. Extrinsic risk factors may reside in the patient care staff (practices of an individual caregiver) or the institution (practices in an entire hospital). While many extrinsic factors contribute to nosocomial infections, the factors that have been most frequently implicated and studied are certain high-risk medical interventions, such as surgical operations and the use of invasive devices (25, 26, 46, 89, 92, 94, 106, 131, 145).

(i) **High-risk medical devices.** There are numerous reasons why the nosocomial infection rate among patients exposed to certain devices is many times greater than that among those not exposed to such devices (76). Patients who require invasive devices may have more severe underlying disease conditions that increase their susceptibility to infections. These devices also provide a pathway for microorganisms from the environment to enter the body, facilitate the transfer of pathogens from one part of the patient's body to another, and act as inanimate foci where pathogens can

TABLE 3. Distribution of major infection sites for all patients and by major services, 1990 through 1992, hospital-wide component, NNIS system

Infection type	% of cases						
	All patients (n = 62,205)	General surgery (n = 26,408)	Medical (n = 26,178)	Newborn (n = 3,220)	Obstetric (n = 2,931)	Gynecology (n = 1,882)	Pediatric (n = 1,586)
UTI	33.1	30.2	42.1	4.2	16.5	39.7	12.7
Pneumonia	15.5	16.4	17.0	14.9	2.3	6.5	12.7
SSI	14.9	24.5	2.3	1.8	45.0	37.2	6.1
Primary BSI	13.1	9.5	14.8	36.1	2.2	3.9	29.7
Other	23.4	19.4	23.8	43.1	34.0	12.7	38.8

proliferate protected from the patient's immune defenses. The decision to use these high-risk devices and for how long should be based on the patient's condition or therapy and not on the convenience of the patient care staff. Policies and procedures to ensure that the devices are used appropriately and safely must be readily available to the patient care staff.

Recommendations for the prevention and control of infections associated with operative procedures and the most commonly used high-risk devices have been published. The most widely disseminated and accepted guidelines are those developed by CDC (12-18). They are currently being revised and updated under the guidance of the Hospital Infection Control Practices Advisory Committee, which is a 12-member committee selected by the Secretary of the Department of Health and Human Services to provide advice and guidance to CDC on hospital infection control issues. CDC recommendations on preventing transmission of blood-borne pathogens in health care settings are also available (19, 20). Guidelines developed by other infection control and

specialty organizations and experts should be reviewed in conjunction with the CDC guidelines when hospitals are formulating their own policies and procedures. Furthermore, the infection control program staff, including laboratorians, should strive to keep the hospital's policies current by reviewing peer-reviewed journals.

(ii) **Operative procedures.** Despite the efforts of surgeons and the operating room team to optimize the patient's condition and the environment for performing operations, SSI constituted approximately 15% of the infections reported to the NNIS system in 1991 by hospitals that collected hospital-wide surveillance data. The overall percentage of nosocomial infections that are SSI has not changed appreciably in the last decade. SSI are a major infection control concern because they are associated with serious morbidity and mortality and high cost (66, 67, 111). Patients who undergo an operation also have higher rates of infection at other sites, such as pneumonia, UTI, and BSI (65). The higher rates are most likely related to the use of high-risk devices such as ventilators, urinary catheters, and central intravascular lines during surgery and in the postoperative period.

The risk of SSI is related to a number of factors. Among the most important are the operative procedure performed, the degree of microbiologic contamination of the operative field, the duration of the operation, and the intrinsic risk of the patient (47, 73). Because infection control practices cannot ordinarily alter or eliminate these risks, SSI rates must be adjusted for these risks before the rates can be used for comparative purposes. An SSI risk index that effectively adjusts SSI rates for most operations has been developed by the NNIS system (27).

Not all infections related to extrinsic risk are preventable, since the benefits of the continued use of a high-risk device or the performance of a necessary operation may outweigh the risk of infection. However, if a hospital is experiencing infection rates in excess of those reported by other hospitals among patients with similar risks, further investigation is warranted to determine whether an infection control problem exists.

Therapeutic and Environmental Pressures

Antibiotics. Antimicrobial agents have had a profound effect on the character of nosocomial infections. Approximately 25 to 35% of hospitalized patients receive systemic antibiotics (88). However, it has become abundantly clear that the major nosocomial pathogens either are naturally resistant to clinically useful antimicrobial agents or possess the ability to acquire resistance. Every major class of bacterial pathogens has demonstrated an ability to develop resistance to one or more commonly used antimicrobial agents (42). Evidence for the altered virulence—whether

TABLE 4. Intrinsic risk factors associated with nosocomial infections

Infection type	Intrinsic risk factors
Primary BSI	Age ≤ 1 or ≥ 60 yr Immunosuppressive chemotherapy Loss of skin integrity (e.g., burn, psoriasis) Severity of underlying illness
Pneumonia	Surgery (particularly high abdominal or thoracic) Chronic lung disease Advanced age Immunosuppressive chemotherapy
UTI	Severity of underlying illness (e.g., diabetes mellitus) Female gender Advanced age
SSI	Severity of underlying illness (e.g., high American Society for Anesthesiology score, diabetes mellitus) Obesity Advanced age Malnutrition Trauma Loss of skin integrity (e.g., psoriasis) Presence of distant infection
Burn wound	Percentage of skin surface burned Advanced age Malnutrition

TABLE 5. Distribution of nosocomial pathogens isolated from major infection sites, 1990 through 1992, hospital-wide component, NNIS system^a

Pathogen	% of isolates					
	All sites (70,411 isolates)	UTI (25,371 isolates)	SSI (11,724 isolates)	BSI (9,444 isolates)	Pneumonia (8,891 isolates)	Other (14,981 isolates)
<i>Escherichia coli</i>	12	25	8	5	4	4
<i>Staphylococcus aureus</i>	12	2	19	16	20	17
CoNS	11	4	14	31	2	14
<i>Enterococcus</i> spp.	10	16	12	9	2	5
<i>Pseudomonas aeruginosa</i>	9	11	8	3	16	6
<i>Enterobacter</i> spp.	6	5	7	4	11	4
<i>Candida albicans</i>	5	8	3	5	5	5
<i>Klebsiella pneumoniae</i>	5	7	3	4	7	3
Gram-positive anaerobes	4	0	1	1	0	19
<i>Proteus mirabilis</i>	3	5	3	1	2	2
Other <i>Streptococcus</i> spp.	2	1	3	4	1	2
Other <i>Candida</i> spp.	2	2	1	3	1	1
Other fungi	2	3	0	1	1	1
<i>Acinetobacter</i> spp.	1	1	1	2	4	1
<i>Serratia marcescens</i>	1	1	1	1	3	1
<i>Citrobacter</i> spp.	1	2	1	1	1	1
Other non- <i>Enterobacteriaceae</i> —aerobes	1	0	1	1	4	2
Group D streptococci	1	2	2	1	0	1
Group B streptococci	1	1	1	2	1	1
<i>Haemophilus influenzae</i>	1	.	0	0	5	2
Other <i>Klebsiella</i> spp.	1	1	1	1	2	1
Other <i>Enterobacteriaceae</i> —aerobes	1	1	1	0	1	1
Other gram-positive aerobes	1	0	2	1	0	1
Viruses	1	0	0	0	1	2
<i>Bacillus fragilis</i>	1	0	2	1	0	0

^a Pathogens that constituted less than 1% of isolates from all sites are not included.

enhanced or diminished—of antimicrobial agent-resistant bacteria versus drug-susceptible organisms is conflicting. However, from a recent review of 175 reported community and nosocomial outbreaks of selected pathogens, mortality, likelihood of hospitalization, and length of hospital stay were at least twofold higher among patients infected with resistant pathogens than among patients infected with susceptible pathogens (68). The interrelationships of antibiotic therapy, intrinsic or acquired resistance of bacteria to antibiotics, and nosocomial infections are complex (36). The use of antimicrobial agents tends to create selective pressure that promotes the emergence of resistant organisms and predisposes patients to colonization with such organisms. This rise in resistant organisms that are notoriously difficult to treat has been facilitated by the increasing use of immunosuppressive drugs and invasive devices and the introduction of new technologic advances (140).

Environment and other factors. Ambient environmental factors such as water, air, and food are among the traditional extrinsic sources of infection, but they are less important in modern hospitals that are required to meet stringent hygienic and engineering standards. Nevertheless, the potential for massive outbreaks still exists when water, air, or food is contaminated with certain pathogens, since they may affect large numbers of people simultaneously. The transmission of tuberculosis and Legionnaires' disease in hospitals is an example of how inadequate environmental controls and the presence of susceptible individuals can contribute to noso-

comial spread of infections (5, 30, 32, 34, 57, 114). Infection with environmental pathogens, such as those on contaminated instruments or equipment, is more likely to occur when hospital personnel fail to follow hospital policy when performing direct patient care.

Universal precautions are techniques used in hospitals to prevent the transmission of blood-borne pathogens between patients and between patients and patient care staff (19, 20). The key premise of universal precautions is that all persons are considered to be infected with a blood-borne pathogen, which requires anyone who is likely to be contaminated with blood and certain other body fluids to use barrier protection, such as gloves, protective eyewear, gowns, and masks. All sharp instruments, such as used needles and scalpels, must be handled so as to prevent injuries and discarded properly. Regardless of whether universal precautions are in force, the patient care staff must not forget the critical role of hand-washing in preventing the transmission of nosocomial infections (17, 133).

NOSOCOMIAL PATHOGENS

Distribution

For all infections reported to the NNIS system by hospitals using the hospital-wide component during 1990 through 1992, *Escherichia coli* and *Staphylococcus aureus* were the

most commonly isolated nosocomial pathogens (Table 5). Although *E. coli* is found in a quarter of UTI cases, it is isolated relatively infrequently from other infection sites. Conversely, *S. aureus* is rarely isolated from UTI but is common at other sites. In BSI, coagulase-negative staphylococci (CoNS) are isolated almost twice as often as *S. aureus*. *Enterococcus* spp. are frequently isolated from UTI, SSI, and BSI but rarely found in the respiratory tract. *Pseudomonas aeruginosa* is isolated from about 1/10 of all infections and appears to evenly affect all of the major sites except the bloodstream, where it is found less often.

Trends

To determine whether the frequency of the most common pathogens isolated from nosocomial infections reported to the NNIS system has changed, we compared the pathogens reported during 1990 through 1992 with those in earlier published reports (125). From 1986 through 1989, *E. coli* was the most common isolate (16%) reported to the NNIS system, followed by enterococci (12%), *P. aeruginosa* (11%), *S. aureus* (10%), and CoNS (9%). Compared with the 1970s, the pathogens associated with nosocomial infections changed dramatically during the 1980s. Unfortunately, the pathogens associated with nosocomial infections were more often difficult to treat with antibiotics. For example, the percentage of infections with *P. aeruginosa* and *Enterobacter* spp. increased, while those with *E. coli* decreased. The reporting of CoNS increased dramatically, particularly for blood isolates, from 9% of all pathogens in 1980 to 31% during 1990 through 1992. Although the changes probably represent a true increase in infections with this organism, there has been an increased propensity to report CoNS in cultures as true pathogens rather than as contaminants, as in the past (134).

EMERGING PATTERNS OF ANTIMICROBIAL RESISTANCE

Soon after the introduction of penicillin into general medical use in the 1940s, it was recognized that bacteria would develop resistance to antibacterial agents. By 1948, most of the staphylococci isolated in British hospitals were resistant to penicillin. As other antimicrobial agents were introduced, organisms resistant to them were isolated from infected patients or from the environment. This has developed into a cycle of antimicrobial agent development, introduction into clinical use, and the development of resistance—often to the point where the antimicrobial agent becomes useless.

Gram-Positive Organisms

The increasing number of antimicrobial agent-resistant gram-positive nosocomial isolates is illustrated by the reports that show an increasing prevalence of *S. aureus* strains resistant to beta-lactam antibiotics in U.S. hospitals (7, 117, 139). Using data from the NNIS system, we recently analyzed the changes that occurred among U.S. hospitals over a 17-year period, 1975 through 1991, in the percentage of *S. aureus* strains resistant to beta-lactam antibiotics and associated with nosocomial infections (112). The percentage of methicillin-resistant *S. aureus* (MRSA) isolates was defined as the number of *S. aureus* isolates resistant to either methicillin, oxacillin, or nafcillin divided by the total number of *S. aureus* isolates for which susceptibility test results for

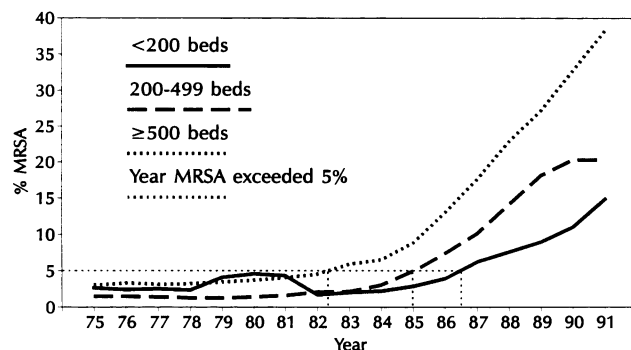


FIG. 2. Temporal trends in percentage of MRSA isolates by hospital size, NNIS system (from reference 112).

these drugs were reported to the NNIS system. Of the 66,132 *S. aureus* isolates tested, 6,986 (11%) were resistant to at least one of these drugs. The percentage of MRSA among all hospitals rose from 2.4% in 1975 to 29% in 1991, but the rate of increase differed among three hospital categories based on number of beds (Fig. 2). In 1991, 15, 20, and 38% of *S. aureus* isolates were MRSA in hospitals with <200 beds, 200 to 499 beds, and ≥500 beds, respectively. The time at which MRSA isolates in each of these size categories rose above the 5% level differed: in 1983 for hospitals with ≥500 beds, in 1985 for hospitals with 200 to 499 beds, and in 1987 for hospitals with <200 beds. This study suggests that the problem appears to be increasing regardless of hospital size, and the control measures advocated for MRSA isolates may need to be reevaluated. These measures were either applied or followed inconsistently or may be ineffective.

More than half of CoNS isolates are resistant to methicillin, oxacillin, or nafcillin, necessitating more expensive and potentially more toxic therapeutic agents. Recent evidence from data reported to the NNIS system suggests that the occurrence of resistant CoNS has increased dramatically in all NNIS system hospitals, regardless of hospital size (125).

As a consequence of the rise in MRSA isolates, empiric vancomycin use in many U.S. hospitals appears to be on the rise (144). Unfortunately, resistance to vancomycin is increasing among *Enterococcus* spp. As of October 1992, 7.9% of all enterococci associated with nosocomial infections among ICU patients reported to the NNIS system were

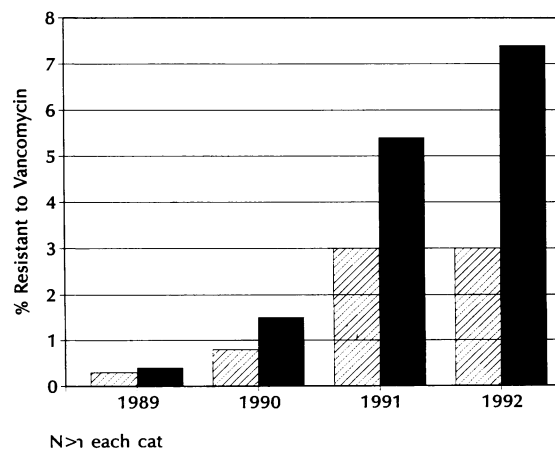


FIG. 3. Percentage of nosocomial enterococci resistant to vancomycin in non-ICU (hatched bars) and ICU (solid bars) patients, by year, NNIS system ($n > 800$ in each category).

vancomycin resistant; this is an increase from 4% of all enterococci isolated from ICU infections in 1991 (Fig. 3). The development of vancomycin-resistant CoNS has been described by others (90, 127). Vancomycin-resistant enterococci and CoNS may serve as a reservoir of resistance genes for a more virulent gram-positive organism, *S. aureus*, which appears to be capable of expressing vancomycin resistance in the laboratory (108). Although CDC has not received any confirmed reports of vancomycin-resistant *S. aureus* among clinical isolates, the development of a vancomycin-resistant *S. aureus* would have disastrous public health consequences, since effective alternative antibiotic treatment may not be available in the United States (23).

Gram-Negative Organisms

In recent years, several reports have emphasized the development of antibiotic resistance among gram-negative bacilli, especially *Klebsiella pneumoniae*, *P. aeruginosa*, and *Enterobacter* spp. These organisms are increasing in incidence among nosocomial pathogens largely because of their ability to express certain resistance phenotypes (125).

In the 1970s and early 1980s, the prevalence of aminoglycoside-resistant gram-negative bacilli increased but was found to vary considerably among individual hospitals (11, 31, 72, 85, 121, 142). More recently, the availability of second- and third-generation cephalosporins and other extended-spectrum beta-lactam agents has shifted attention from the aminoglycosides toward a different set of resistance mechanisms for these gram-negative bacilli (1, 49, 118). Concern over resistance to beta-lactam agents among nosocomial gram-negative pathogens has heightened recently because of the increased availability and use of these drugs, particularly cephalosporins. The development of extended-spectrum beta-lactamases has been explosive; more than two dozen beta-lactamases among gram-negative bacilli have been described since 1983 (116). *K. pneumoniae* serves as a distinctive example. In one hospital, the minor DNA base pair substitutions in the gene for a beta-lactamase, termed SHV-1, showed dramatic changes in the substrate specificity of the new enzyme, which evolved into an enzyme giving resistance to cefotaxime, which had been used in large quantities (107). The changes observed in the gene from the nosocomial isolate were easily reproduced in the laboratory. Moreover, the gene was plasmid borne and capable of transfer at high frequency.

Other types of resistance among nosocomial gram-negative bacilli also became apparent in the 1980s. *Enterobacter* spp. were considered initially susceptible to cefamandole but began to develop resistance during therapy due to a spontaneous derepression of intrinsic chromosomal type I beta-lactamase (110, 124). This mechanism of resistance is widespread. In a recent six-hospital study of 136 cases of *Enterobacter* bacteremia, one-third of the isolates were resistant to all cephalosporins and penicillins tested (24). Recent data from the NNIS system suggest that resistance to the third-generation cephalosporin ceftazidime increased from 31% in 1987 to 38% in 1991 (9).

Imipenem is the broadest-spectrum parenteral antimicrobial agent that is commercially available and has remained a useful drug for gram-negative bacilli that have developed resistance due to a spontaneous derepression of intrinsic chromosomal type I beta-lactamase. However, in our study of isolates reported by NNIS system hospitals from 1986 through 1990, resistance to imipenem occurred in 11% of 4,026 nosocomial *P. aeruginosa* and in 1.3% of 1,825 noso-

comial *Enterobacter* spp. isolates (49). Our analysis concurs with a previous report that imipenem resistance is more common among ICU isolates than among isolates from non-critical care units (81). We also found that imipenem resistance among *P. aeruginosa* was more common in teaching hospitals and in isolates from the respiratory tract than in those from the bloodstream, urinary tract, or surgical wounds. Although the factors associated with imipenem resistance among *Enterobacter* spp. were similar to those among *P. aeruginosa*, the low rate of imipenem resistance and the relatively small numbers of isolates in our study resulted in a low probability of detecting any but very large differences.

In contrast to *P. aeruginosa*, imipenem resistance among *Enterobacter* spp. did not increase significantly from 1986 through 1988 to 1989 through 1990. Among NNIS system teaching hospitals, a 25% increase in imipenem resistance was seen between the two periods when we controlled for the other risk factors in the logistic regression model. The reasons for the difference between the stable trend among *Enterobacter* spp. and the increase in imipenem-resistant *P. aeruginosa* isolates are unknown but may be due to differing rates of mutation for membrane-associated porin protein production between the two genera (10, 137, 138). Although no data on antibiotic use are available, it is reasonable to assume that imipenem use has increased in NNIS system teaching hospitals since the drug was released in the United States in 1986. It is also possible that the increase in imipenem use was greater among teaching hospitals than among nonteaching hospitals.

Although the pharmaceutical industry continues to develop new antimicrobial agents to combat resistant strains, the number of new agents has decreased because the cost of research and development is high. Once on the market, newer agents are expensive, usually exceeding the cost of older antimicrobial agents, and they drive up health care costs. Most of these newer agents are too expensive for use in developing countries, forcing them to use cheap but ineffective antimicrobial agents or limiting the availability of therapy for all infected patients. It is imperative that antimicrobial agents in clinical use, and those scheduled for release soon, be used judiciously. Since the number of new antimicrobial agents in the marketplace is decreasing, new antimicrobial agents that simply replace those that are no longer effective cannot be relied upon to deal with the problem of resistance.

ROLE OF THE LABORATORY IN INFECTION CONTROL

The success of the hospital's infection control efforts hinges to a large extent on the active involvement of the laboratory in all aspects of the infection control program. Laboratory personnel should understand why infection control is necessary, the approaches being taken by the hospital's infection control program to meet its objective to reduce nosocomial infections, and how the laboratory can support and cooperate with the program.

Development of Infection Control Programs

In the 1940s and '50s, severe *S. aureus* pandemics caused substantial morbidity and mortality in U.S. hospitals. In part because of these pandemics, the Joint Commission on Accreditation of Healthcare Organizations (JCAHO) in 1958 first recommended that hospitals appoint infection control

committees (80). However, faced with growing numbers of drug-resistant pathogens, increasing use of high-risk medical interventions, and the introduction of more immunosuppressive agents and therapies, hospitals, along with regulatory and accrediting organizations, began to realize that a committee alone cannot adequately deal with the problem of nosocomial infections. In most hospitals, the committee directs the infection control activities, but its members, already responsible for other hospital functions, usually do not have the time or the skill to perform the day-to-day duties of infection control. In the 1960s, infection control programs were begun in U.S. hospitals, and a new health care professional, the infection control practitioner (ICP), was introduced. In the United States, there is now an ICP in almost every hospital (40). According to a recent study, most ICPs are registered nurses, although some have other professional backgrounds; 9% are either medical technologists or respiratory therapists (6). The Association for Practitioners in Infection Control, a professional organization for infection control, was organized in 1972 and changed its name to the Association for Professionals in Infection Control and Epidemiology in 1993. Physician hospital epidemiologists, who serve as medical directors of the infection control program, particularly in larger hospitals, are growing in number and have their own professional organization, the Society for Hospital Epidemiology of America (35, 58, 129).

The JCAHO has had considerable influence on the adoption of formal infection control programs in hospitals. As part of its accreditation standards, JCAHO prescribes the broad elements of infection control programs but gives hospitals wide leeway in designing their own infection control programs (79). JCAHO standards stipulate key organizational structures and functions, which determine the ability of health care institutions to provide quality health care (113). In 1986, the JCAHO unveiled its Agenda for Change, which is a major research and development project that is expected to culminate in 1996 with the introduction of indicators to assess the actual performance of hospitals (78). Clinical indicators, including eight in infection control that are currently undergoing phase II pilot testing, are expected to radically change the JCAHO survey process for accreditation (83, 109). None of the clinical indicators for infection control specifically assess the quality of the microbiology laboratory.

The CDC, through its guidelines development, nosocomial infection surveillance methodology, outbreak investigations, and laboratory studies, has provided much of the scientific and epidemiologic basis for infection control in the United States. It also organized some of the early training for ICPs and hospital epidemiologists. Its landmark study on the efficacy of nosocomial infection control (SENIC Project) demonstrated that, to be effective, nosocomial infection programs must include the following components: (i) organized surveillance and control activities, (ii) adequate number of trained infection control staff, and (iii) a system for reporting SSI rates to surgeons (64). Other organizations have made important contributions to infection control, particularly the American Hospital Association (3), the American Society for Microbiology, and specialty groups, such as the American College of Surgeons and the Association of Operating Room Nurses. Individual states also promote infection control through regulations in their health codes and hospital licensure standards.

Surveillance of Nosocomial Infections

Surveillance is defined as "the ongoing, systematic collection, analysis, and interpretation of health data essential to the planning, implementation, and evaluation of public health practice, closely integrated with the timely dissemination of these data to those who need to know" (21). Surveillance, which is an essential element of an infection control program, provides the data to identify infected patients and determine the site of infection and the factors that contributed to the infection. When infection problems are recognized, the hospital is able to institute appropriate intervention measures and evaluate their efficacy. Surveillance data are also used to assess the quality of care in the hospital. If the data collected are to be most useful for decision making, the hospital should focus on their most important and predominant problems and use surveillance methods that adhere to sound epidemiologic principles.

The nosocomial infection surveillance system may be sentinel event based or population based or both. A sentinel infection (or sentinel group of infections) is one that clearly indicates a failure in the hospital's efforts to prevent infections and, in theory, requires individual investigation (128). Denominator data are usually not collected in sentinel event-based surveillance. Sentinel event-based surveillance will identify only the most serious problems and should not be the only surveillance system in the hospital. Population-based surveillance, that is, surveillance that is done on patients with similar risks, requires both a numerator (the infection) and denominator (number of patients or days of exposure to the risk). If the infection rates are to be used for interhospital comparisons, the rates must be adjusted for patients' intrinsic and extrinsic risks of infection (105). To calculate risk-adjusted rates from population-based surveillance data, corresponding risk factors in both the numerator and denominator must be collected. The risk factors may be patient characteristics such as underlying disease conditions, or they may be procedures or devices used to diagnose or treat the patient.

The NNIS system employs a population-based surveillance system that provides risk-adjusted rates that can be used for interhospital comparisons (37). Data are collected for four surveillance components that target different populations of inpatients: (i) all patients in the hospital (called hospital-wide), (ii) patients in the ICU, (iii) patients in the high-risk nursery, and (iv) patients who undergo an operative procedure. Except for the hospital-wide component, important and specific risk factors are collected for the population of patients monitored. For example, in the ICU surveillance component, data are collected on the type of ICU and the total number of days that patients are exposed to a urinary catheter, central vascular line, or ventilator; these are called device-days. Risk-adjusted infection rates from aggregated data reported by hospitals participating in the NNIS system have been published (27, 50, 76).

Requirements for a surveillance system. A hospital should have clear goals for doing surveillance. Furthermore, these goals must be reviewed and updated frequently to meet new infection risks in changing patient populations, the introduction of new high-risk medical interventions, and changing pathogens and their resistance to antibiotics. A surveillance system should include the following elements.

Trained personnel. A typical ICP will spend about half of her or his time performing surveillance (39, 130). The ICP should have, at minimum, knowledge about clinical patient care, epidemiology, and microbiology. Unfortunately, some

hospitals appoint individuals to the infection control position but do not provide them with training to adequately perform infection control functions. Courses in infection control are available through the Association for Practitioners in Infection Control and Epidemiology and its local chapters. Individuals who meet certain time and practice qualifications and successfully pass a written examination can be certified in infection control (22).

Accepted definitions and criteria for nosocomial infections, risk factors, and other outcomes. Criteria for all data collected in the surveillance system must be defined and must be used uniformly by all who perform surveillance. Even when standard criteria are used, such as those published by CDC (48, 70), they should be reviewed and approved by the hospital's infection control committee.

Readily available sources of data for identifying infections. The infection control program must have access to all patient and hospital records and should have the full cooperation of all hospital personnel and departments to obtain the necessary data to conduct routine surveillance or investigate an outbreak. For routine surveillance, the infection control program uses laboratory and clinical data for two reasons: case finding, i.e., screening for patients with possible infections; and determining the site of infection, associated risk factors, and outcomes. The surveillance system should not rely solely on other hospital personnel, such as coders, to collect data to identify infected patients because the application of some infection criteria is complex and patient medical records often are not complete (98). The diagnostic practices of the physicians practicing in the hospital are an important factor in the ability of the infection control program to detect infections, since most infections are identified through microbiologic cultures and other laboratory tests (61). If most of the patients in the hospital are treated empirically, without cultures being done, the infection control program cannot use culture results as its primary source for detecting infections and must instead adopt clinically based infection criteria. The infection control program staff, through various hospital committees, may be able to influence physicians' diagnostic practices to encourage appropriate culturing and other testing.

Accurate and complete denominator data. Where to obtain denominator data and how to collect them vary among hospitals, depending on the sources available in the hospital and the resourcefulness of the infection control program in gaining the cooperation of the patient care staff and other hospital departments. In a recent survey that we conducted of NNIS system hospitals, only 30% of the ICPs reported that the staff in the patient care areas collect the denominator data for them (38).

Analysis and dissemination of data to those who need the information. Surveillance is incomplete until the data are analyzed, interpreted, and disseminated to those who need to have the information (33). Although the value of reporting back surveillance findings was demonstrated in the SENIC Project, surveillance data are underused in many hospitals. The lack of risk-adjusted rates for most hospitals, which make the data difficult to interpret, may be an important reason why surveillance data are not useful.

Confidentiality of the data. The infection control program must be able to assure the hospital staff and physicians that the surveillance data will be used appropriately. Surveillance should be used to improve the quality of patient care and should not be used as a tool to punish or grade individuals, departments, or services without scrupulously protecting institutional and professional reputations. Several states have adopted laws protecting such data.

Selection of patients for monitoring. Traditionally, nosocomial infection surveillance systems have routinely monitored all patients in the hospital for infections at all sites and have used the overall infection rate to describe the magnitude of the infection problem (43, 45, 51, 71, 74, 86, 122). While an overall rate may provide an estimate of the infection problem, the value of such surveillance systems has recently been questioned. In order to monitor all patients for infections, a wide range of information sources must be reviewed in an ongoing fashion, and low-risk and high-risk patients are given equal time. Otherwise, the surveillance intensity will be uneven, resulting in an unacceptably low case-finding sensitivity. Furthermore, because most of the time is spent finding infections, there is little time left to collect data to adjust the rates by risk. A more efficient and effective alternative to hospital-wide surveillance is to focus on patients with the highest risk for infection. With the exception of the hospital-wide component, the NNIS system surveillance components are examples of surveillance protocols that target high-risk patients.

Strategies for identifying infected patients. Surveillance for nosocomial infections should be done prospectively, that is, patients should be actively and continuously monitored for infections while they are still in the hospital. The case-finding methods used to detect infected patients depend on the sources of information available in the hospital. In most hospitals, the microbiology laboratory reports are the most useful and efficient source for initial case finding (56). However, the microbiology laboratory should not be the sole source for case finding since cultures are not done for all patients with infections. Other sources of information to detect possible infections include the nursing care plan cards (Kardex) (146), antibiotic orders in the pharmacy, radiologic reports, autopsies, and verbal reports from patient care personnel. Like laboratory results, most of these require verification with other data, such as clinical findings recorded on the patient's medical record, to determine an infection site.

Use of surveillance data for continuous quality improvement. Over the last decade, the use of nosocomial infection rates as a basis for measuring quality of care has received considerable attention. The SENIC Project estimated that one-third of the nosocomial infections that occurred in the United States during 1975 through 1976 could have been prevented by optimal infection surveillance and control programs (64). To assist hospitals in using surveillance as a more effective tool to reduce nosocomial infection rates, Haley integrated surveillance with the concepts of management by objective and coined the term surveillance by objective (59). He designed an approach for the hospital staff to collaboratively set goals for reducing infections at specific sites and to concentrate their efforts on the elements of the infection control program found to be most effective by the SENIC Project (60). The results of the SENIC Project coincided with the efforts of the government and other purchasers of health care to control costs by demanding that the health care industry assess and be accountable for the quality of care provided (29, 119, 120, 123).

Continuous quality improvement is a general model for improving quality through continuous evaluation of performance in order to identify opportunities to improve the product or outcome (28). It is an approach that has been widely adopted by industry, including the health care industry, to provide high-quality products and services at a competitive and affordable price (126). Because the collection of reliable data is an essential element of this evaluation

process, nosocomial infection surveillance can make an important contribution to continuous quality improvement in the hospital.

Hospitals use data to assess their quality of care by comparing their infection rates with external benchmark rates or by comparing changes in rates over time in their own hospitals. Many hospitals assume that any difference in the rates represents the success or failure of the patient care staff or institutional practices in preventing nosocomial infections. While this may be true, there are other factors that could account for the differences in the rates. First, surveillance definitions or techniques may not be uniform among the hospitals or may be used inconsistently over time, causing variations to occur in sensitivity and specificity in infection case finding. Second, inaccurate or insufficient information about clinical and laboratory evidences of infections in the patient's medical record may seriously affect the validity and utility of the infection rate. The microbiology laboratory plays an essential role as a source of information on nosocomial infections and is discussed later. Third, the rates may not be adjusted for patients' intrinsic risks for infection. These risks are usually outside the control of the hospital and vary from hospital to hospital but are important factors in determining whether the patients will develop an infection. For example, a hospital with a large proportion of immunocompromised patients would be expected to have a population at higher intrinsic risk for infection than a hospital without such a population of patients. The unsuccessful attempts to compare unadjusted mortality rates (53, 77) are reminders to those comparing infection rates that they must also pay attention to risk-adjusted infection rates (44, 62). Finally, the size of the population at risk (e.g., number of patients, admissions and discharges, patient-days, or operations) may not be large enough to calculate rates that adequately estimate the "true" rates for the hospital.

Although it may not be possible to fully correct for these factors, hospitals should be aware of how they can affect the infection rate and take them into consideration when interpreting the data.

Specific Laboratory Support Functions

The microbiology laboratory should be actively involved in the infection control program. As the source of microbiologic culture information, the laboratory must provide easy access to high-quality and timely data and give guidance and support on how to use its resources for epidemiologic purposes. The services that the infection control program can offer to the laboratory include functioning as a liaison to the clinical services to improve the quality of specimens sent to the laboratory and promoting appropriate use of cultures and other laboratory tests. It can also assist the laboratory with its system for monitoring antimicrobial agent susceptibilities by identifying the pathogens that are of nosocomial origin.

Interaction of the laboratory with the infection control program. A current and thorough discussion of the role of the laboratory in infection control can be found in the text *Hospital Infections* (102). Other publications on this subject are also informative (141, 143). In brief, the microbiology laboratory can support the infection control program in the following ways.

Ensure high-quality performance in the laboratory. Because the surveillance system ordinarily uses the results of cultures and other tests ordered by physicians for the diagnosis and treatment of patients, the surveillance pro-

gram benefits when the laboratory performs high-quality work on clinical specimens. Additional laboratory tests may be necessary for epidemiologic purposes, but this is rare and should be discussed thoroughly with the infection control program first. The cost of cultures and other tests performed for epidemiologic purposes is usually not charged to the patient.

Designate at least one person from the microbiology laboratory to be the consultant to the infection control program and to serve as a member of the infection control committee. Any activity of the infection control program that involves the laboratory should be coordinated through a designated person. Conversely, this representative should keep the infection control program informed about changes in the laboratory that may affect surveillance and other aspects of the program. This person should be selected for his or her knowledge of and interest in infection control.

Make laboratory test results available in an organized, easily accessible, and timely manner. The infection control program depends on the cooperation of the laboratory in making laboratory data accessible. The design of the laboratory's record-keeping system should accommodate the needs of the infection control program and should be developed in collaboration.

Provide training on basic microbiology for the infection control program staff. Most beginning ICPs do not have a working knowledge of microbiology and will require training before they are able to effectively use the laboratory services for the infection control program. The ICP will need to be taught how to interpret the results of cultures and other tests in order to conduct surveillance.

Monitor laboratory results for unusual findings. The laboratory should watch for clusters of pathogens that may indicate an outbreak, the emergence of multidrug-resistant organisms, and the isolation of highly infectious, unusual, or virulent pathogens. The laboratory staff is usually the first to recognize these unusual events or trends, and reporting them early to the infection control program may avert a more serious problem.

Use environmental cultures judiciously. Microbiology laboratories are often asked to perform environmental cultures to assess microbial contamination of inanimate objects or the level of contamination in certain areas of the hospital. Such culturing must be coordinated with the infection control program to ensure that it is performed only when indicated and that the specimens are processed appropriately. In the past, environmental cultures were performed extensively in most hospitals (2, 96, 99). Routine environmental cultures are recommended only for monitoring autoclaves and water used to prepare dialysis fluid (17). Environmental cultures, including personnel cultures, should not be done unless epidemiologic evidence clearly indicates an environmental source of the pathogen. Under these circumstances, information about the etiologic agent can often lead to a clearer understanding about the source of the infection and mode of transmission. Occasionally, a culture of a device used on an infected patient can locate the source of the infection; for example, the semiquantitative method for culturing intravascular catheter tips to determine a vascular site infection has been found to be useful (95). When associated with local infection, colony counts of more than 15 CFU have a 15 to 40% association with concordant BSI (93).

Store isolates that may require further identification for epidemiologic purposes. In collaboration with the infection control program, the laboratory should develop a system for storing epidemiologically important strains of pathogens

from nosocomial infections by subculturing them and maintaining them in a viable state. The collection should be reviewed frequently, and isolates should be discarded when they are no longer needed.

Take proper action when contamination of a commercial product is suspected. Contamination of commercially produced products or devices during manufacture or transportation is rare. If intrinsic contamination is suspected, the hospital laboratory should not attempt to culture the product or device, since special techniques and equipment are required. Instead, immediately call the toll-free USP Device Complaint number (800-638-6725). If substantial patient disease or mortality is occurring, notify your state health department. The Hospital Infections Program at CDC can assist in an investigation if invited to do so by the state health department.

Epidemiologic uses of laboratory findings. Laboratory findings are used to support epidemiologic evidence of the spread of a common organism between patients, employees, and the environment. Strain clonality permits the infection control program to confirm the association between patients (hosts) and reservoirs for the microorganisms of interest and to determine possible modes of transmission. The mode of transmission, reservoir, and nature of the susceptible hosts are easier to determine if a single strain (clone) is involved, because the mode of transmission or reservoir may not be the same for multiple strains.

The determination of strain clonality may lie in routine tests performed by the microbiology laboratory or the variety of techniques that molecular biology offers to infection control (103). However, the use of these techniques should support an epidemiologic investigation rather than lead it. For example, laboratory resources to assess colonization of hospital personnel (or patients) should never be used unless epidemiologically indicated. The degree to which organism identification is routinely carried out can be important. In general, identifying an isolate as *Pseudomonas cepacia* provides more useful epidemiologic information than identifying the organism only as "*Pseudomonas* species," since a variety of related bacilli could be included in the latter group but have different reservoirs or modes of transmission. Reporting of the biotype of microorganisms, i.e., pattern of response in biochemical reactions, is occasionally valuable in differentiating frequently encountered organisms (52).

Whenever a new procedure for the identification of microorganisms is introduced, the laboratory should consider the procedure's potential ability to assist or hinder the infection control program in tracking the incidence of infections. For example, nucleic acid probes are useful for direct detection of pathogens in clinical samples but do not provide information about antimicrobial agent susceptibility or strain type, which are often important to the infection control program (136). Therefore, if the pathogen is epidemiologically important, it may be necessary to culture a specimen. Serologic testing is a technique that most infection control programs are not using fully and appropriately. The laboratory should assist the infection control program by making clear the strengths and weaknesses of different assays when they use them for epidemiologic purposes.

Epidemiologic typing of microorganisms. To investigate whether microorganisms are clonal or not, the laboratory usually examines the results of species identification and biochemical tests and patterns of susceptibility to antimicrobial agents. However, more specialized techniques are occasionally required to type certain organisms (41, 100, 115, 135). Two of these, biotyping and antimicrobial agent sus-

ceptibility testing, were discussed earlier. Another technique, phage typing, is based on an organism's susceptibility to bacteriophages and is used most often for *S. aureus*. Because only a limited number of nosocomial pathogens exhibit bacteriophage susceptibility, this procedure has a relatively narrow application. Furthermore, because considerable experience is required to reliably perform phage typing, the procedure should be done by a reference laboratory (75). Another technique, serotyping, is used for the typing of gram-negative bacilli, especially *P. aeruginosa* (54). Still other typing techniques that use molecular biology have added to the variety of typing techniques available. Among the most common are plasmid profiles and the digestion of plasmid or genomic material with restriction endonucleases (101).

The appropriate use of these typing methods, some of which are redundant, is important. The key factor in deciding which method to use involves examination of how much discrimination the method can add. Surprisingly, some of the simplest, least expensive, and most available typing methods may be the best. For example, in a study of infections with CoNS, antimicrobial agent susceptibility profiles, biotyping, phage typing, and plasmid profiling were performed. The antimicrobial agent susceptibility profiles proved to be the most discriminating (91). Test results may vary when tests are performed by inexperienced technicians or when specimens are processed in different batches. The microbiology laboratory should decide which of the typing tests it can do reliably on site and which should be sent to appropriate reference laboratories.

CONCLUSIONS

Recent changes in the economics of health care have changed the infection risk of patients in the hospital. While progress has been made in preventing and controlling nosocomial infections, these infections nevertheless continue to cause morbidity and mortality, leading to increased health care costs. Infection control programs should focus on preventing infections in patients who are at highest risk of infection because of exposure to certain procedures and medical devices.

Antibiotic resistance continues to be a major threat in hospitals. Vancomycin-resistant CoNS and enterococci are becoming more common. The emergence of vancomycin-resistant *S. aureus* could have disastrous consequences. The resistance of gram-negative organisms to the second- and third-generation cephalosporins and other extended-spectrum beta-lactam agents is increasing. The growing resistance to imipenem is particularly troublesome because it has the broadest spectrum of the commercially available parenteral antimicrobial drugs that are effective against *P. aeruginosa*.

The microbiology laboratory should be involved in all aspects of the infection control program. Particularly important are its roles in the hospital's infection surveillance system and in assisting the infection control program to effectively and efficiently use laboratory services for epidemiologic purposes. Through the infection surveillance system, the infection control program collects data on nosocomial infections in the hospital, the pathogens and their patterns of antimicrobial agent resistance, the factors that contributed to the infections, and their outcomes. The purposes of surveillance are to identify possible infection problems, monitor infection trends, and assess the quality of care in the hospital.

Tracking infection rates is necessary to compare the hospital's infection experience with that at other hospitals or at its own hospital over time. To make valid comparisons, the infection rates must be adjusted for the most important intrinsic and extrinsic risks of infection. When risk-adjusted infection rates are compared, significant variations in the rates may suggest the need for further investigation to identify possible infection control problems.

Much has been learned in the past 30 years about how epidemiologic techniques can be used to prevent and control nosocomial infections (147). Other programs to measure outcomes of hospital care will benefit from the experiences of the infection control program as hospitals meet the continuing challenge to improve the quality of patient care.

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